SBSS Demonstrator: A Space-Based Telescope for Space Surveillance and Tracking

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ABSTRACT

This paper presents the capabilities of a Space-Based Space Surveillance (SBSS) demonstration mission for Space Surveillance and Tracking (SST) based on a micro-satellite platform. The results have been produced in the frame of ESA's "Assessment Study for Space Based Space Surveillance Demonstration Mission" performed by the Airbus Defence and Space consortium.

The assessment of SBSS in an SST system architecture has shown that both an operational SBSS and also already a well-designed space-based demonstrator can provide substantial performance in terms of surveillance and tracking of beyond-LEO objects. Especially the early deployment of a demonstrator could boost initial operating capability and create a self-maintained object catalogue. Furthermore, unique statistical information about small-size LEO debris (mm size) can be collected in-situ.

1.0 INTRODUCTION

The objective of the ESA study "Assessment Study for Space Based Space Surveillance Demonstration Mission (Phase A)" was to analyse the feasibility of an optical space-based space surveillance (SBSS) demonstration mission and of a subsequent operational mission. Once demonstrated, such a space-based capability would be an ideal contributing asset for an overall Space Surveillance and Tracking (SST) system. SST is part of SSA (Space Situational Awareness) and covers the detection, tracking and cataloguing of space debris and satellites. The design of a dedicated SBSS demonstration mission including the payload was performed.

2.0 BENEFITS OF SPACE-BASED TELESCOPES

The strengths of space-based telescopes for SST are:

- Consecutive observations during 24 hours: Independent of weather, atmosphere , day/night
- Full longitudinal GEO belt coverage with one sensor enabling catalogue generation and maintenance (see Flohrer et al. [5]).
- Tracking in all orbital regions (LEO, MEO, GTO, Molniya, NEOs) for orbit refinements
- Vicinity to LEO small debris enables in-situ measurements
- No geographical and -political restrictions as for ground-based assets
- Scalable performance via # of S/C
    - one sensor provides significant capability

- enhanced performance via constellation of identical S/C
- even as hosted P/L on other constellations

Such benefits have been shown by the US and Canada, having operated SBSS assets and continuing such operations with success.

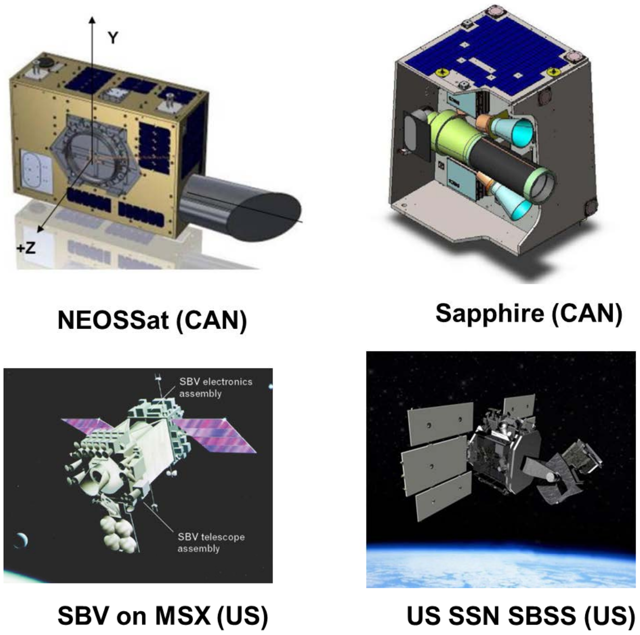

Figure 1: US & Canada successfully operate SBSS assets [2], [3], [4], [5].

3.0 DEMONSTRATOR VS. OPERATIONAL SBSS

In a top-down approach, main operational SBSS mission goals have been derived from the ESA SST System Requirements (SRDs, [6]):

- Build-up a GEO object catalogue from scratch via one spacecraft and maintain it
- Achieve GEO coverage for objects ≥ 0.4 m and partial coverage of other regions
- Achieve accuracy and timeliness as in SRDs
- Perform tasked tracking in all orbit regions
- Detection of small LEO debris ≥ 1 mm
- Size estimation and light curve analysis

For these goals, an operational system concept has been derived trading a multitude of design options. Details about the operational mission design are not provided in this paper, but are reflected in the scaled-down demonstrator, which is presented in the following.

The main idea for the SBSS demonstrator is to map the operational mission onto a concept that fits low technological risk, re-use as much as possible, short development timeframe and low costs. The demonstration goal is therefore no classical technology demonstration but includes

- Demonstration of the end-to-end chain from object detection to catalogue generation
- Sharing of representative data products with other SSA stakeholders.
- De-risking of the operational concept
- Enabling early SST capability

Main differences between the SBSS demonstrator and the operational mission are

- Micro-satellite platform around 150 kg total
- Smaller optical instrument
- Piggy-back launch (orbit constraints)
- 5 years lifetime (goal)

Apart from these differences, the observation strategies and observation accuracy from the operational mission are kept the same.

4.0 DEMONSTRATOR INSTRUMENT

The instrument is a smaller version of the operational one, downscaled to fit a micro-satellite platform or to be used as hosted-payload. Its TMA design enables a large 3°x3° FOV for efficient survey while still providing a 20 cm aperture for sufficient sensitivity. The sensor uses the visible spectrum (0.3 – 1.0 µm) and on-board data reduction is performed to limit the data volume for the nominal frame period of 1.5 s/frame.

Table 1: Properties of the demonstrator instrument.

Instrument	Value
Aperture diameter	200 mm
Field of View	3°x3°
Detector	2k x 2k
Pixel iFOV	5 arcsec
Nominal frame period	1.5 s/frame
Mass	34 kg
Power	42 W

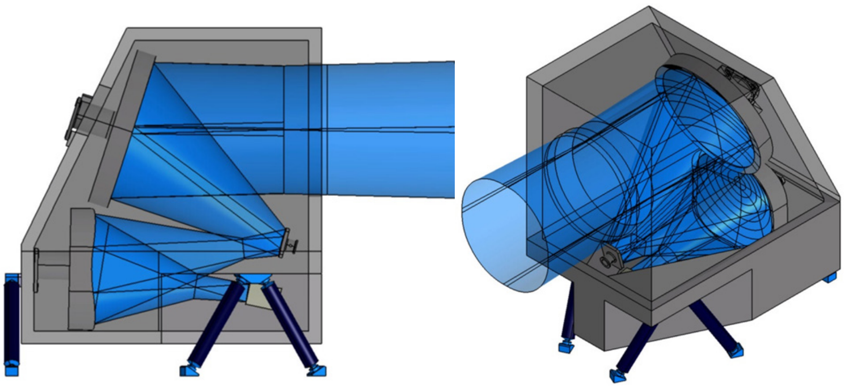

Figure 2: SBSS demonstrator instrument.

5.0 SUITABILITY OF MICRO-SATELLITES

Trades and comparisons of different available micro-sat platforms (SSTL-150, TET-X, Myriade, Proba) were performed. In particular, the adaptations needed for implementing the SBSS mission were analysed along with TRL, pointing stability, agility, data handling and transmission, payload embarkation (volume, power, mass), launcher compatibility, propulsion, post-mission-disposal, etc., to name a few of the assessments. The different buses show individual advantages and drawbacks, but as general conclusion, the examined platforms can be adapted well to the demonstrator mission. Other emerging platforms are deemed suitable as well

For mission performance, dawn-dusk sun-synchronous orbits ≥ 700 km are ideal; piggy-back launch opportunities for such orbits are quite frequent.

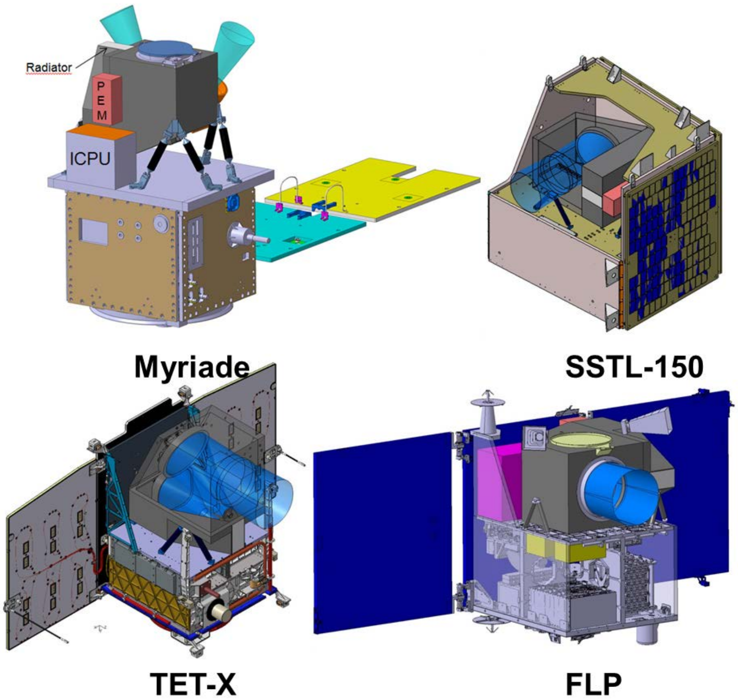

Figure 3: Demonstrator instrument on different micro-satellite platforms

6.0 GEO OBSERVATION STRATEGY

The observation strategy for GEO surveillance exploits the geometrical distribution of geosynchronous objects in space. It is possible to detect and re-visit the entire GEO population via observing a limited search window in right ascension and declination. Leak-proof fences can be implemented by systematic pointing of the telescope's FOV in a step-and-stare manner. GEO objects cannot slip through such a pattern undetected if the scanning frequency is chosen accordingly. This leak-proof property ensures the reliable and timely generation of a complete catalogue. Such concepts have been proposed (and successfully demonstrated) for ground-based systems [6]. Two fence locations (see figure below) are required in order to obtain automatic follow-up observations. These are essential in order to achieve the accuracy and timeliness needed to catalogue formerly unknown objects. The best illumination conditions are given for anti-sun pointing (e.g. pointing next to the Earth shadow), resulting in low phase angles for observed objects. The telescope itself is fixed and all pointing is performed by the platform.

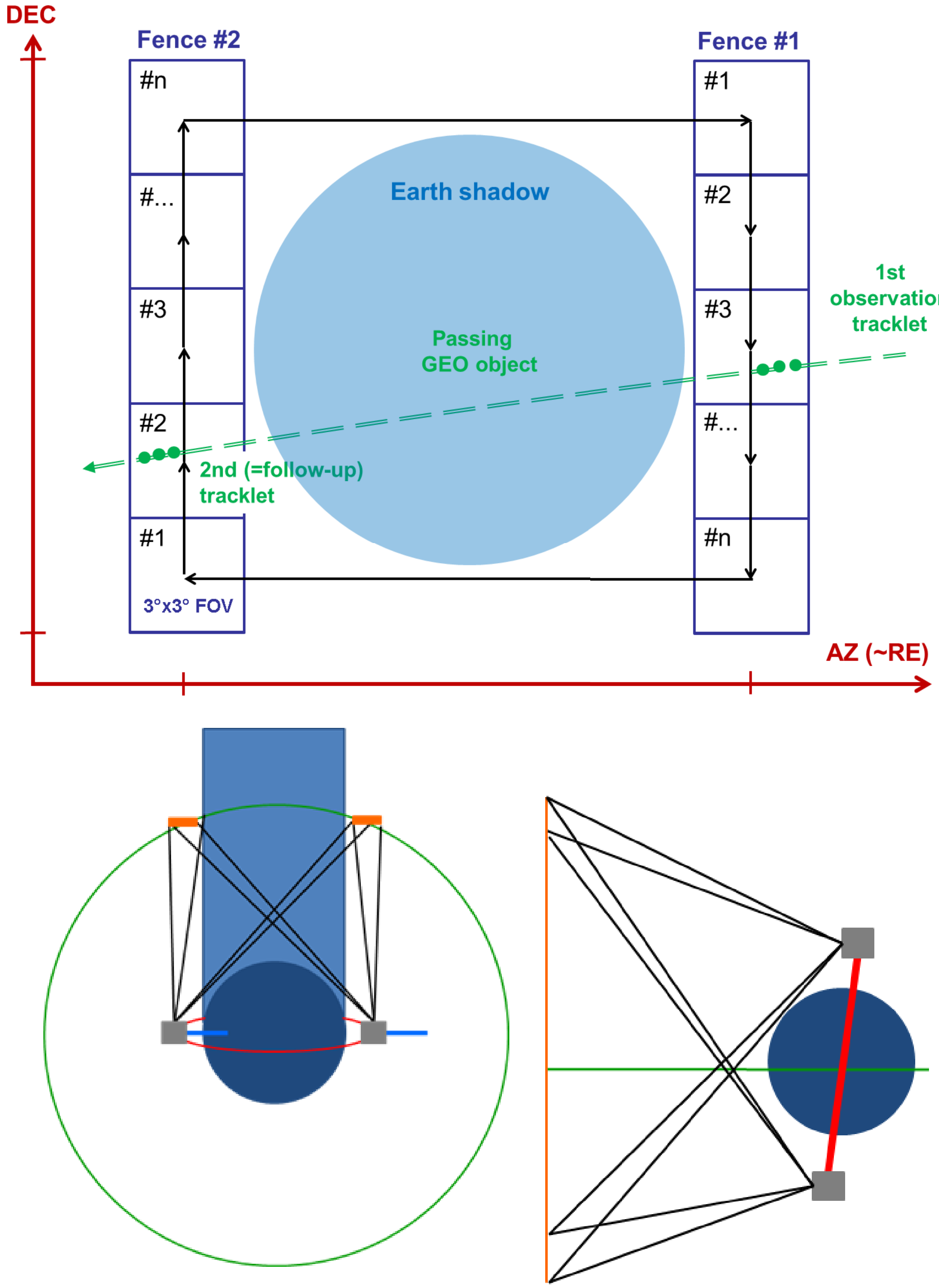

Figure 4: GEO observation strategy

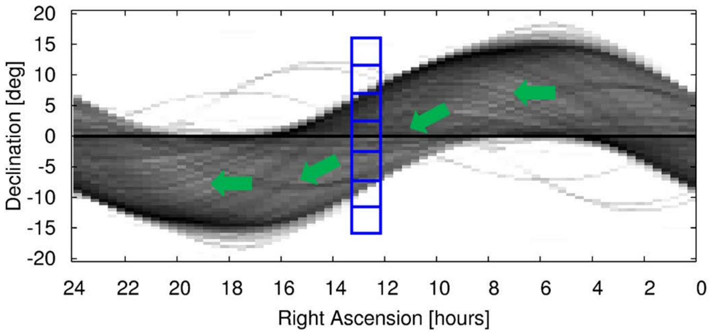

Figure 5: Geometry and dynamics of GEO object belt.

7.0 TRACKING OBSERVATION STRATEGY

As second operational mode, the SBSS demonstrator will perform tasked tracking in regions from LEO to beyond-GEO. Tasked tracking is similar to the telescope pointing for surveillance, however, the line of sight (LOS) is aimed to a volume of space where known object will pass through, potentially adapted to the expected angular rate. Orbits can be then systematically refined on request via respective observations. Tasked tracking is possible in a wide observation envelope (see below figure), provided the objects are sufficiently illuminated by the Sun. The fidelity of the tracking performance depends on the detailed satellite design (power, attitude control, thermal control, instrument's stray light rejection capability).

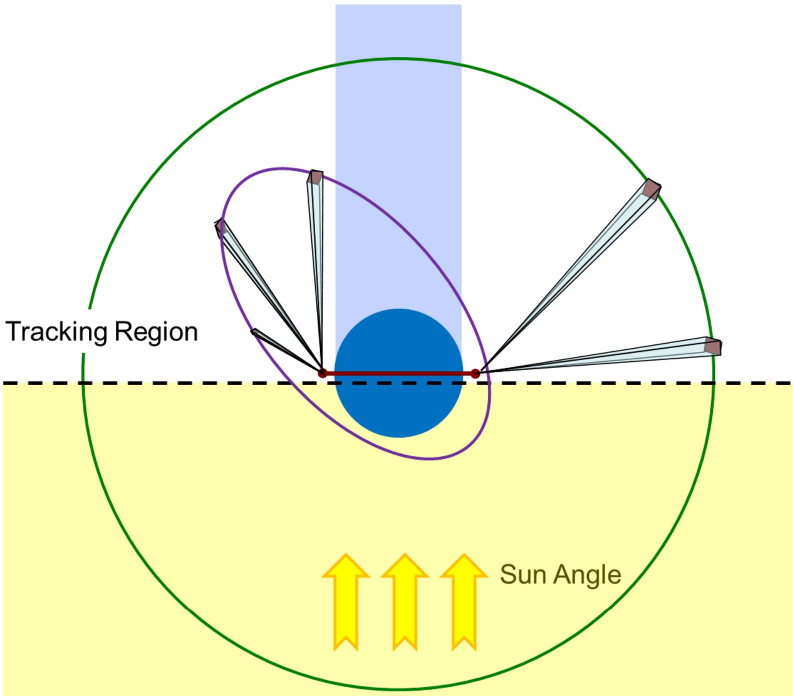

Figure 6: Tasked tracking observation strategy

8.0 DEMONSTRATOR SURVEY PERFORMANCE

A variety of simulations were performed showing that the small SBSS demonstrator is already able to generate and maintain an object catalogue. The achieved performances are close or often even compliant to the operational goals and SST system requirements. The larger operational SBSS achieves full performance in GEO. In other orbital regions, SBSS achieves partial but not full coverage in terms of cataloguing. In constellation, system performance can be further enhanced.

Main drivers for the difference between demonstrator and operational mission are the instrument field-of-view (3° vs. 5° FOV) and platform pointing agility. If these differences can be further reduced for the demonstrator, increased performance can be expected.

Table 2: Compliance of SBSS regarding the GEO surveillance performance.

ESA SST SRDs i1r4	SBSS Demonstrator	Operational SBSS	Constellation: Demonstrator & Operational SBSS
GEO objects ≥ 0.4/1.0m	Compliant	Compliant	Compliant & enhanced performance
Cataloguing with a spherical accuracy envelope of 2.5 km	Coverage, accuracy & timeliness can be traded.	Compliant	
Cataloguing within 72 hours after the first observation		Compliant	
Pre-cataloguing within 72 h	Compliant	Compliant	

9.0 DETECTION OF LEO SMALL DEBRIS ≥ 1 MM

The additional objective of detecting small-sized debris as small as 1 mm size in LEO entered the study upon request by ESA. This topic, being part of ESA's CleanSpace initiative which assesses the environmental impact of ESA activities, was fully supported by Airbus DS and integrated into the SBSS demonstrator concept.

Small debris observations are not to be confused with the cataloguing goal of SSA's Space Surveillance and Tracking segment. On the contrary, the objects of interest are the ones being too small and too faint for conventional SST. Not cataloguing, but detection and coarse orbit determination is the goal.

Better knowledge of this "sub-catalogue" population comprising vast numbers of particles way beyond the number of catalogued objects is valuable for the improvement of space debris environment models and, hence, serves the reduction of satellite vulnerability.

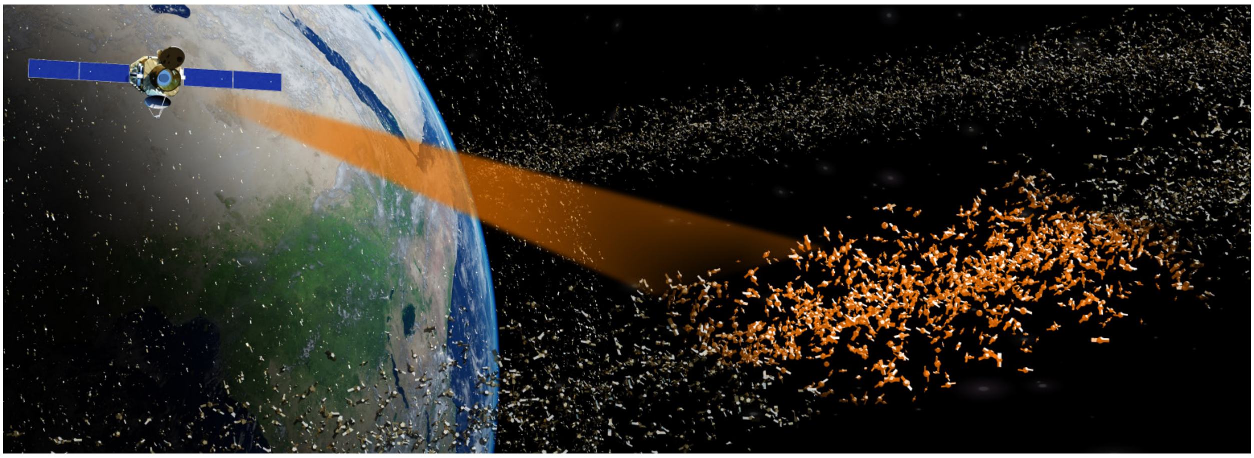

Figure 7: "In-Situ" monitoring of small debris in LEO, artist's sketch.

Small debris detection performance for the SBSS demonstrator instrument has been estimated via simulations using the ESA PROOF-2009 tool. The anti-sun pointing strategy for GEO survey has been kept as it was deemed similarly favourable for illumination conditions. Detection rates in the order of hundreds in the 1mm-1cm size regime and several thousand objects larger 1 cm have been estimated for one day of observation.

10.0 TRL

The proposed SBSS demonstrator mission is not a classical technology demonstration, but rather an end-to-end test for the SST detection and data processing chain. As the required technology is mature, no developments are required for the baseline configuration, in particular for surveillance and tracking. Optional elements such as custom CMOS detectors would require moderate developments.

Note that the current ESA GSTP "Optical In-Situ Monitor"activity tackles the development of an E2E processing pipeline as a follow-up activity to the presented "SBSS Phase A" study. Particular focus is put on the on-board detection of faint and fast objects and therefore the capability of detecting low SNR streaks of small LEO debris. The project team, consisting of prime Airbus DS, AIUB and Micos, develops for this purpose a laboratory breadboard system which is composed of a scene generator (emulating movement and brightness of debris objects and stars), a breadboard instrument with similar detection characteristics of the envisaged flight model and the according on-board and on-ground processing.

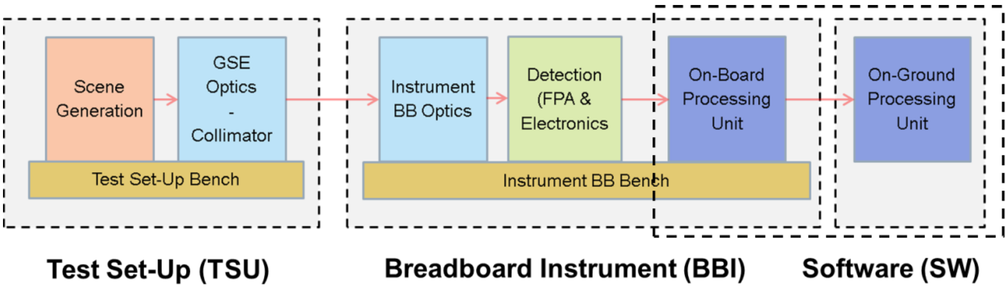

Figure 8: End-to-end detection chain in the "Optical In-Situ Monitor" breadboarding activity.

11.0 CONCLUSION

A system design has been performed for both operational space-based space surveillance and an according demonstration mission.

The major findings of the "Assessment Study for SBSS Demonstration Mission (Phase A)" are in summary:

- High performance already for the SBSS Demonstrator:
  - GEO catalogue
  - Tracking in all orbits
  - LEO small debris during SST mission
- Re-use & mature technologies: Low risk, short schedule
- Micro-sat platforms are suitable for SBSS demo mission
- No classical technology demonstration but end-to-end chain until product generation
- Scalable/enhanced performance
  - one sensor provides significant capability
  - enhanced performance via constellation of identical S/C
  - also as hosted P/L on other constellations

The SBSS activity is continued in ESA's "Optical In-Situ Monitor" project.

12.0 REFERENCES

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